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BEACH EROSIONAL HOT SPOTS: TYPES, CAUSES, AND SOLUTIONS

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PURPOSE: This Coastal and Hydraulic Engineering Technical Note (CHETN) discusses the types, causes, and example solutions of erosional hot spots (EHSs; singular EHS) by which they can be identified and measures that can be taken to prevent or cope with the erosion in an effective way. An EHS is an area with high erosion rate as compared to the adjacent beach or to expectations for the behavior of the beach. EHSs located adjacent to inlets can compromise beach nourishment performance or performance of the site as a placement area for beach-quality dredged material. Possible types of EHSs are extended to cover geologic or regional scales.

BACKGROUND: Wide awareness and systematic study of EHS areas began in the 1990's with experience gained in long-term maintenance of large beach fills at many sites, comprehensive beach-monitoring programs, and efforts to minimize costs while maintaining project design specifications. An EHS is an area that experiences sediment transport potential without having adequate sediment supply. EHSs erode more rapidly than the adjacent beaches or more rapidly than anticipated during design. EHSs can be quantitatively and qualitatively defined by several metrics. Examples are loss of beach width (recession rate), loss of sediment volume (erosion rate), percentage of fill remaining of the amount placed, and perception of how a fill should perform relative to adjacent beaches or to historic rates (e.g., Stauble 1994; Raichle, Elsworth, and Bodge 1998).

Some coasts to be nourished are sediment deficient, obscuring the presence of latent EHSs that emerge once material is in place. In these situations, designers must be alert to conditions with potential of producing EHSs and account for them. The causes of EHSs need to be identified to determine the most appropriate action for placement.

The original definition of an EHS (e.g., Bridges 1995; Dean, Liotta, and Simón 1999) was intended to cover erosional phenomena that were unanticipated and primarily local (e.g., a well-identified area located within a beach fill). However, in the relatively short time of several years, the generating mechanisms or causes of most types of EHSs have been identified. Also, long beach fills are being constructed and considered, indicating that the definition should encompass regional extent as well as local and isolated areas.

Knowledge of coastal processes appears adequate to understand or predict the occurrence of most types of EHSs and to formulate appropriate actions, which could range from acceptance of the erosion to complete arresting of the erosion over the time scale of the project. Because EHSs drive the performance of placed material, and because planning strategies should account for areas with high erosion rates, here the definition of EHSs is extended or generalized to encompass any area with a high erosion rate, as judged by comparison to rates at adjacent or similar beaches. Eliminating the requirements of an unanticipated problem and/or a localized area adds several EHS types. A prominent example is erosion on the down-drift side of a jetty, that would not be considered in the original sense, but which would substantially control the cost of a maintenance of a beach fill or expected life of material placed on the beach as least-cost dredged material disposal. The existence of EHSs can lead to public concern even if the overall project is functioning properly, adding motivation to account for EHSs in initial design to assure more uniform project performance.

Typically, but not always, an EHS persists over a time interval of an engineering project or ownership of private property. The duration depends on the cause and is one of the classification criteria applied to EHS as discussed below.

The reader is referred to Stauble (1994), Bridges (1995), Raichle, Elsworth, and Bodge (1998), Bodge, Gravens, and Srinivas (1999), Dean, Liotta, and Simón (1999), Liotta (1999), and Weber (2000) for additional information and viewpoints, case studies, and direction to other publications. Also, the concept of erosion cold spot (ECS) areas, which are anomalous accumulations of beach material or advance of the shoreline as compared to adjacent beaches or expected by experience, is not discussed in detail here (see, e.g., Stauble 1994; Smith and Ebersole 1997; Dean, Liotta, and Simón 1999). Depending on the cause of the EHS, the redistribution of the eroded material may create or preserve one or more ECSs.

This CHETN identifies and classifies all known types of EHSs and points to possible underlying causes as presently understood. EHSs can be prevented in many situations or predicted in others, allowing preventive or mitigation measures to be incorporated in design. In some cases, knowledge of the temporary or periodic appearance of and EHS might be sufficient to accept the phenomenon without remedial measures. EHS types requiring investigation to achieve quantitative predictive capability for EHSs are identified.

CLASSIFICATION OF HOT SPOTS: EHSs can be classified by general properties, such as:

1. Duration of existence;
2. Lateral extent;
3. Processes responsible for the erosion;
4. Predominant erosion mechanism as longshore or cross-shore transport;
5. Whether the type of EHS can be predicted or remedied.

These properties are considered here for EHSs already identified in the literature and for other EHSs presented in this CHETN. Table 1 lists all known types of EHSs and the leading causes.

Bridges (1995) compiled the first eight types in Table 1, subsequently expanded to twelve types by Dean, Liotta, and Simón (1999). However, EHS Type 7, "headlands and encroachments" can be modified to encompass three subtypes, after Bodge, Gravens, and Srinivas (1999). These first two-cited publications refer to sources where some of the types and causes were first reported. Table 1 is not in order of possible frequency of occurrence or of severity, and it was prepared to be compatible by type of EHS and in chronology of presentation with previous work. Also, names of some of the types given in the original references were modified slightly.

Table 1. EHS type and cause

Type	Cause of Erosion
1. Dredge selectivity	Variable sediment size or fall speed fall speed alongshore
2. Residual structure-induced slope	Legacy beach slope of pre-existing structure (typically, groin)
3. Wave transformation over borrow pits	Wave transformation (divergence, reflection) and associated longshore current (see Type 11 for natural counterpart)
4. Gaps in bars	Wave focussing; rip current creation (?) (see Type 18)
5. Mechanically placed fill	Less fill placed as compared to adjacent sections hydraulically filled
6. Profile lowering in front of seawalls or cliffs	Sediment deprived; adjustment to equilibrium profile
7. Headlands and encroachments[1]	Encroachment of development in the nearshore; uneven coastal relief; change in orientation of the coast
8. Residual fill bathymetry	Local wave focussing
9. Permanent offshore loss	Sediment lost offshore without possibility to return, as through reefs or to submarine canyons
10. Non-uniform offshore translation of beach	Local wave focussing; areas offshore of high and low waves
11 Non-uniform offshore bathymetry	Nearshore borrow sites; hard-bottom outcrops
12. Borrow pit located within active profile	Sediment transported offshore
13. Updrift barrier	Blockage of longshore transport
14 Relict inlet offset	Headland effect (Type 7) and bathymetry change (Type 11) associated with a past (relict) inlet
15. Translatory longshore sand waves	Periodic discharges of sediment from rivers or bays; periodic breakup of ebb shoals
16. Standing and random longshore sand waves	Seasonal changes in wave climate over irregular offshore/nearshore topography
17. Isolation of beach from longshore transport inputs	Uneven input and output; reduction or elimination of sediment supply
18. Rip currents on open beach or near groins, jetties	Sediment transported offshore

[1]Includes local abrupt changes that are artificially created, headlands, and unfavorable shoreline orientation with respect to dominant wave direction.

Because Types 1-12 have been documented in three University of Florida reports (Bridges 1995; Dean, Liotta, and Simón 1999; Weber 2000), emphasis is given to Types 13-18. Table 2 summarizes EHSs by dominant direction of transport, duration, and lateral extent. Some of the types could be grouped together through similar general causes. For example, non-uniformity in bathymetric contours or in wave focussing might be combined. However, because specifics can greatly differ, for example, as naturally occurring instead of artificially induced, it is beneficial to treat them separately at the present stage of understanding.

Dredge selectivity. EHSs are expected if a material with different sediment sizes is placed alongshore (with the finer material experiencing greater relative erosion). Significantly different grain sizes might be present in one offshore borrow site or among multiple borrow sites. Different locations on the beach may receive significantly different sediment sizes because of random withdrawal of sediment during pumping, a cost-reduction incentive to reduce pumping distance, efficiency in pumping finer sediments longer distances, or because of other reasons. Locations receiving finer sediments will erode faster, predominantly through cross-shore transport. This process will continue until the finer material is transported away or is covered by coarser material. Development of EHSs by this process can be reduced by specifying an acceptable range in grain size or by overfilling. One strategy is to cover the finer sediment with a coarser cap (Kieslich and Brunt 1989).

Residual structure-induced slope. This process has been identified for groins and may also be applicable to detached breakwaters. A groin will tend to hold the upper beach profile, but it cannot prevent removal of sediment seaward of its tip as erosional processes continue. If the groin is removed and over-steepening of the more-offshore profile is not recognized, a greater amount of fill will move offshore to re-establish the profile. Recognizing the profile mismatch and supplying sufficient additional fill volume can mitigate this type of local EHS.

Wave transformation over borrow pit. If borrow material is mined in relatively shallow water (determined by the ratio of depth at the borrow pit to the length of the predominant waves), the pit will act as a lens and redirect waves by refraction and, possibly, by reflection, diffraction, and dissipation. A persistent non-uniform wave climate will be imposed along the beach, and the resultant longshore transport will preferentially redistribute sediment to create hot spots and cold spots. Because waves diverge from a borrow pit, the shoreline in the direct lee of the pit is expected to accumulate sediment. This EHS type is a special case of Type 11, "Wave transformation over offshore bathymetry,"

Combe and Soileau (1987) documented shoreline response to borrow pits located too close to shore at Grand Isle, LA. The resultant cuspate shoreline was subsequently predicted by refraction analysis (Gravens and Rosati 1994). Such situations can be avoided by conducting a refraction analysis as part of the design process to determine allowable location, dimensions, and depths of borrow pits (e.g., Kraus et al. 1988; McKenna, Brown, and Kraus 1995).

Table 2. EHS type, dominant transport direction, and associated time and space scales

Type	Dominant Transport Direction	Duration[1]	Lateral Extent
1. Dredge selectivity	Cross shore	Short-medium	Local
2. Residual structure-induced slope	Cross shore	Short – medium	Local
3. Wave transformation	Alongshore	Medium	Local
4. Gaps in bars	Alongshore	Short-medium	Local
5. Mechanically placed fill	Cross shore	Short	Local
6. Profile lowering in front of seawalls or cliffs	Cross shore	Persistent	Local
7. Headlands and encroachments	Alongshore	Persistent	Local – project wide
8. Residual fill bathymetry	Alongshore	Short	Local – project wide
9. Permanent offshore loss	Cross shore	Persistent	Local
10. Non-uniform offshore translation of beach	Alongshore	Short	Local
11 Wave transformation over non-uniform offshore bathymetry	Alongshore	Persistent	Local – project wide
12. Borrow pit located within active profile	Cross shore	Medium – persistent	Local
13. Updrift barrier	Alongshore	Persistent	Local – project wide
14 Relict inlet offsets	Alongshore	Medium	Local
15. Translatory longshore sand waves	Alongshore	Short – medium	Local, but moving
16. Standing and random longshore sand waves	Alongshore	Short – medium	Local
17. Isolation of beach from longshore transport inputs	Alongshore; Cross shore	Persistent	Local
18. Rip currents on open beach; near groins and jetties	Cross shore	Short	Local

[1]Short = order of year; Medium = order of several years; Persistent = life of typical project, property ownership, or longer (geologic time scale)

Gaps in bars (also called breaks in bars). Breaking waves typically form one or more longshore bars along the coast. The bar system is not always uniform alongshore or two-dimensional, with gaps in the bars formed as the nearshore bottom becomes more three-dimensional. Waves can enter the gaps and approach closer to shore before breaking. The direct incidence of higher waves through the gap and their spreading by diffraction produces a three-dimensional circulation pattern and erosion directly leeward of the gap (Fig. 1). Gaps might be produced by rip currents by random non-uniformity in waves alongshore, or by other causes. If the gaps appear randomly, then erosion is expected to be temporary at a given location. If the gaps are produced by rip currents, it is possible that their location might be semi-permanent, because rip currents often tend to appear in the same location, or oscillate cyclically along the shore (Davis and Fox 1972). This EHS type is expected to remain as long as the gap in the bar remains.

Figure 1. Gaps in bars (marked with arrows) allow higher waves to approach closer to shore, which proceed by diffraction through the gaps.

Mechanically placed fill. It is possible that some portions of a beach fill may be placed mechanically and other portions hydraulically. Also, design experience with the longevity of hydraulic fills may be transferred inappropriately to projects involving mechanical fill. Because some portion of the sediment-water slurry pumped during a hydraulic fill will move offshore in the course of achieving the design cross section, a hydraulically placed project profile will receive some portion of overfill. In contrast, mechanically placed material will have little or no overfill. All other factors being equal, because of the disparity in amount of material placed, a mechanically placed fill will undergo greater adjustment across shore in achieving equilibrium. Dean, Liotta, and Simón (1999) state that the void ratio for mechanically placed material tends to be greater than that of hydraulically placed fill, indicating that mechanically placed material would produce less dry beach width after equilibration and consolidation for the same initial bulk volume of sediment.

Profile lowering in front of seawalls. At a beach that has experienced long-term erosion in front of a seawall, the existing beach profile may be lower than at the surrounding beach. Extra fill should be placed in front of such as seawall to assure achievement of the design width after sediment moves seaward on the profile to return it to equilibrium condition.

Headlands and encroachments. Waves and currents spread sediment alongshore to produce a locally straight shoreline. However, on many beaches, natural projections into the water (headlands) or constructed projections of short length (such as buildings and scenic viewing areas) exist. Fill placed in front of such hard protrusions or headlands will erode and have less width than the adjacent beach on the sides that is set back from the headland or encroachment.

Figure 2 shows a section of Monmouth Beach, NJ that projects seaward of a seawall that follows the coastal trend. Groins hold the local beach in this area. Smith and Kraus (1999) recommended that no modifications of the groins be made to increase their sand-retention efficiency. Through shoreline change numerical modeling they found that a beach fill to be placed to the south (updrift) would act as a feeder beach. The alternatives were quantified by the number of temporary landward violations of the shoreline past a trigger distance that would normally dictate placement of fill. The violations were temporary, until feeder material arrived.

Residual fill bathymetry. If material is placed irregularly alongshore and seaward of the depth of closure, then the nearshore contours will be altered by the presence of the fill. Wave refraction over irregular contours will tend to cause a systematic pattern of convergence and divergence of breaking waves (see Type 11). Different wave heights and directions along the beach will produce areas of varying erosion and accretion – until the residual material disperses.

Figure 2. Monmouth Beach, NJ, September 1996

Permanent offshore loss. Losses of littoral material to submarine canyons has been long documented on the coast of CA (e.g., Everts et al. 1987), and material can be lost as well to deep navigation channels, such as to the channel system located offshore of Sandy Hook, NJ. On a local scale, this process was identified by Raichle, Elsworth, and Bodge (1998) for a nourished beach in Broward County, Florida. Sediment appeared to be transported offshore and over or through a reef. The reef acted as a rectifier, allowing sediment to move offshore but not over it and onshore.

Wave transformation by offshore translation of beach fill. Dean, Liotta, and Simón (1999) postulate that a beach fill with irregular translation offshore will create a non-uniform distribution in wave energy alongshore because the offshore bathymetric contours will not be uniform. EHS's are expected to occur leeward of concentrations of wave energy and ECS's to occur at locations of reduced wave energy.

Wave transformation by offshore bathymetry. Wave refraction diagrams developed even prior to the modern computer age showed that irregular bottom contours produce wave convergence and divergence along the coast. Here, offshore refers to the area from deep water for the characteristic wave period of the coast to the outer edge of the typical surf zone or the average-annual depth of closure. EHS Type 3, borrow pit within active zone, is a example.

Examination of long-term shoreline change data for many locations reveals highly variable rates of change and locations of significantly elevated rates of erosion. Along coastal Delaware, several EHSs correspond to irregular shoreface bathymetry in the form of linear sand shoals or ridges. McBride and Moslow (1991) postulated that the sand ridges are remnants of ebb shoals. The sand ridges focus wave energy on segments of the shoreline by wave refraction. Galgano (1989) demonstrated that these segments of the shoreline erode at much higher rates and in some instances can be classified as EHSs. Further, Moody (1964) and Kraft, et al. (1975) established that these sections of the shoreline erode at significantly higher rates and are frequently breached by tidal inlets. Leatherman, et al. (1989) confirmed similar behavior at Ocean City, MD. In this case wave refraction induced by a large linear sand ridge caused higher rates of erosion in the vicinity of the 1933 Ocean City Inlet breach site. Galgano (1998) demonstrated that the area of the inlet breach experienced rates of erosion double that of the surrounding beaches. Mohr, Pope, and McClung (1999) showed that variable erosion rates along a beach nourishment project on Presque Isle, Pennsylvania (Lake Erie) were related to irregularities in offshore bathymetry.

Borrow pit located within active profile zone. A nearshore borrow site, such as created by mining the fillet at an updrift jetty, may be located in the active profile, shallower than the average annual depth of closure, h_*. In this situation, sediment moving offshore during storms will tend to fill the borrow pit until the equilibrium profile is achieved. Filling of the pit will translate the profile landward.

In Fig. 3, the solid line denotes the equilibrium profile that would result in the absence of the borrow pit, and the dashed line denotes the profile after adjustment to fill the borrow pit by cross-shore transport. Suppose a volume V per unit length alongshore is removed from a borrow site. It can be shown by equating volumes that the profile will translate landward a distance $\Delta x \cong V/h_*$ under the assumption that the distance translated is small compared to the distance from the shoreline to the location of the depth of active movement. For example, if $V = 30$ m^3/m and h_*. = 6 m, then Δx = 5 m. The adjustment is expected to take several months to years, depending on where the pit is located and possible infilling by longshore processes.

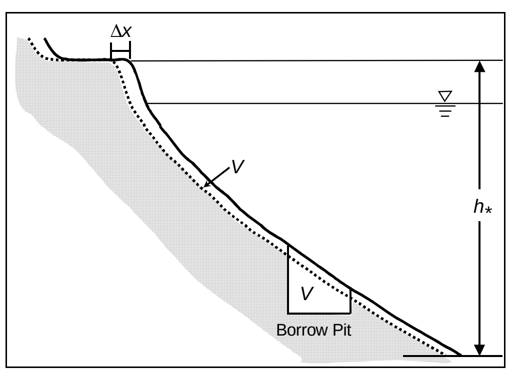

Figure 3. Definition sketch for borrow site located on active profile.

Updrift barrier. Littoral processes at tidal inlets are the most dynamic and complex element of the barrier island system, and beaches located directly downdrift of inlets have long been viewed as high-erosion areas (i.e., EHSs). Both natural and stabilized inlets exert influence along adjacent shorelines and within large-scale coastal compartments. At stabilized inlets, jetties extend offshore for hundreds of meters and block the transport of sediment, inducing a notable response on the adjacent beaches, and potentially altering the configuration of a natural barrier island (e.g., Assateague Island, MD). Likewise, the tidal jet produced by an unstabilized inlet can disrupt the flow of littoral sand and modify the coastal configuration for tens of kilometers downdrift (e.g., Chincoteague Inlet, VA – see Fig. 4). In mesotidal conditions, inlet stability and behavior have been shown to directly alter barrier island morphology. Dean and Work (1993), Nummedal et al. (1977), FitzGerald et al. (1978), and Mehta (1996) concluded that tidal inlets are responsible for most of the beach erosion along U.S. East Coast barrier-island chains. Galgano (1998) demonstrated that nearly 70 percent of the shoreline along the mid-Atlantic coast is significantly influenced (erosion or accretion) by tidal inlets.

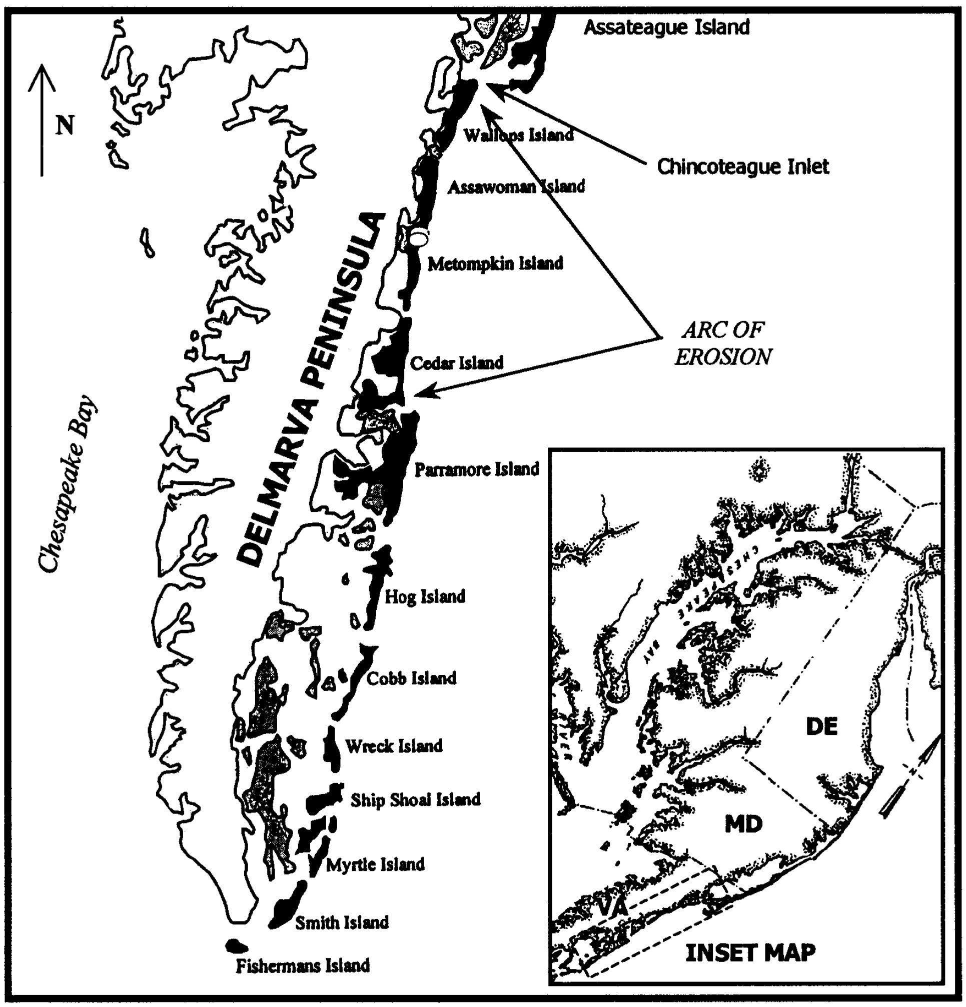

Figure 4. Regional view and shoreline change rates in vicinity of Chincoteague Inlet, VA.

The literature indicates that beaches located directly downdrift of inlets experience significant erosion and can be termed broadly as EHSs (e.g., Leatherman, et al. 1987; Dean and Work 1993; Douglas and Walther 1994; Fenster and Dolan 1996; Mehta 1996; Bruun 1996). These regional

EHSs, which typically measure 10-16 km in length (Galgano 1998), are not limited to inlets stabilized by jetties. In fact, unstabilized or natural inlets can cause EHSs that extend laterally at mega-scales, extending some 30-40 km downdrift (Finkelstein 1983; Galgano 1998). Chincoteague Inlet (Fig. 4) at the southern terminus of Assateague Island is one such example. It is a naturally existing microtidal inlet and traps a large volume of longshore sediment (estimated at 115,000 m^3/year) updrift of Chincoteague Inlet. A large cape-like feature (Fishing Point) has developed and the updrift sand impoundment has a pronounced influence on the shoreline by sand-starving the barrier islands to the south. The blockage of longshore sediment by the inlet has starved the downdrift beaches to the extent that a 5-km offset is observed on the island to the south. Shoreline recession rates of more than 10 m/year are observed for tens of kilometers to the south. The net result is a highly concave shoreline extending 35 km south of the inlet. Such a regional trend of high erosion rate and shoreline adjustment must be taken into account in managing that coast.

Relict inlet offsets. A relict tidal inlet can have a marked impact on shoreline rates-of-change and may manifest itself as an EHS for a period of decades until the shoreline re-equilibrates in conformance with the offshore contours. In microtidal conditions, unstabilized inlets exhibit similar behavior. An idealized example is given in Fig. 5. Sand is transported alongshore to the inlet and constricts the inlet throat. The resulting decrease in flow area increases the current velocity and scour potential in the channel. Because sand is added to mainly one side of the inlet, the down drift side erodes preferentially, causing the inlet to migrate with a characteristic offset in planform. Once the inlet closes, however, the updrift offset functions as a headland (Type 7). Wave energy is focused by refraction, resulting in significantly higher rates of erosion until the updrift offset aligns with the rest of the shoreline. An example of this type of EHS is illustrated by an analysis of long-term shoreline change data for Jones Beach Island New York. Long-term shoreline change data for Jones Beach Island suggest that the eastern half of the island is an EHS, with shoreline recession rates in excess of 4 m/year observed.

The long-term shoreline behavior of central Jones Beach Island is detailed in Fig. 6. An active tidal inlet was located in the center of the island, causing a substantial offset in beach planform prior to closing in 1900. Substantial downdrift offset in the 1835 shoreline was caused by interruption of the longshore transport system. The updrift (eastern) side of the inlet is offset seaward by approximately 1 km. Following inlet closure, the beach responded by reorienting, and the updrift offset exhibited high rates of erosion as the shoreline naturally straightened. Shoreline change rates prior to and after inlet closure are given in Fig. 7. Long-term shoreline change rates (1835-1991) illustrate the presumed EHS. However, shoreline behavior after reorientation (1941-1991) is less erosional. The attenuated erosion is a consequence of the geomorphic reorientation of the shoreline and beach nourishment during the 1960s and 70s.

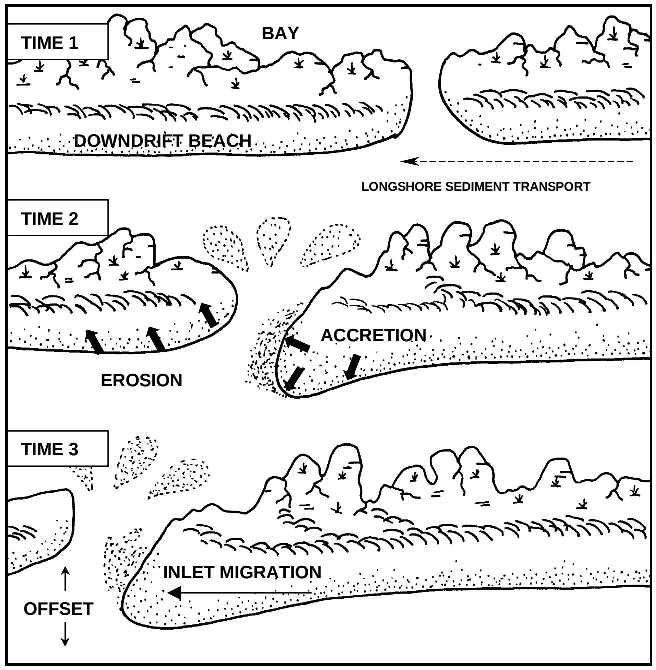

Figure 5. Development of a relict inlet and shoreline offset.

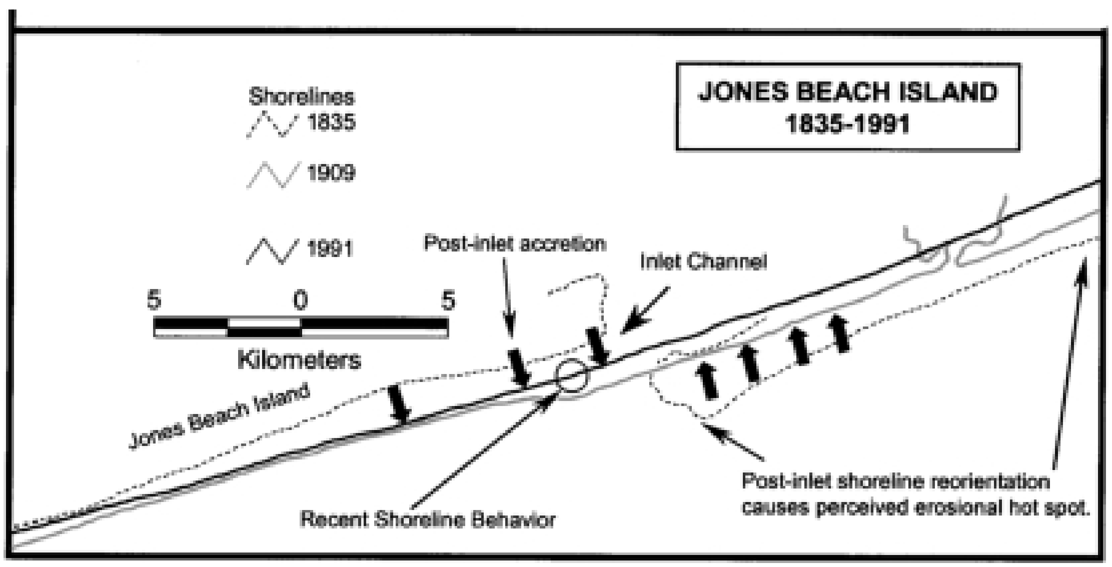

Figure 6. Evolution of Jones Beach Island, Long Island, NY, a relict inlet

Translatory longshore sand waves. Large undulations in the shoreline have been observed to propagate in the net direction of longshore transport (e.g., Grove, Sonu, and Dykstra 1987; Inman 1987; Thevenot and Kraus 1995). A longshore sand wave (LSW; plural LSWs) moves as an organized form similar to a solitary water wave and can be preceded by an erosion wave that may extend alongshore farther than the wave's crest (accretionary portion). Translatory LSWs have long-shore extent on the order of a kilometer and crest elevation (distance of crest from trend of shoreline) of tens of meters. A common cause of LSWs is a sudden injection or impulse of sediment to the beach. Examples are attachment of a small ebb shoal or bar to shore, a river discharge, or other release of a compact slug of sediment. LSWs move with speeds on order of 1 km/year; along Southampton beaches on the south shore of Long Island, NY (Fig. 8) the speed of LSWs was seasonally dependent, in accordance with expected magnitudes in seasonal longshore sediment transport.

If an erosion wave arrives to a particular site, it may persist a year or more. LSWs can move through groin fields as well, as calculated by Hanson, Thevenot, and Kraus (1996). Mohr, Pope, and McClung (1999) document "sand slugs" (LSWs?) traveling through a field of detached breakwaters. A temporary fill would mitigate the erosion wave at a vulnerable area; otherwise, passage of the wave can be estimated.

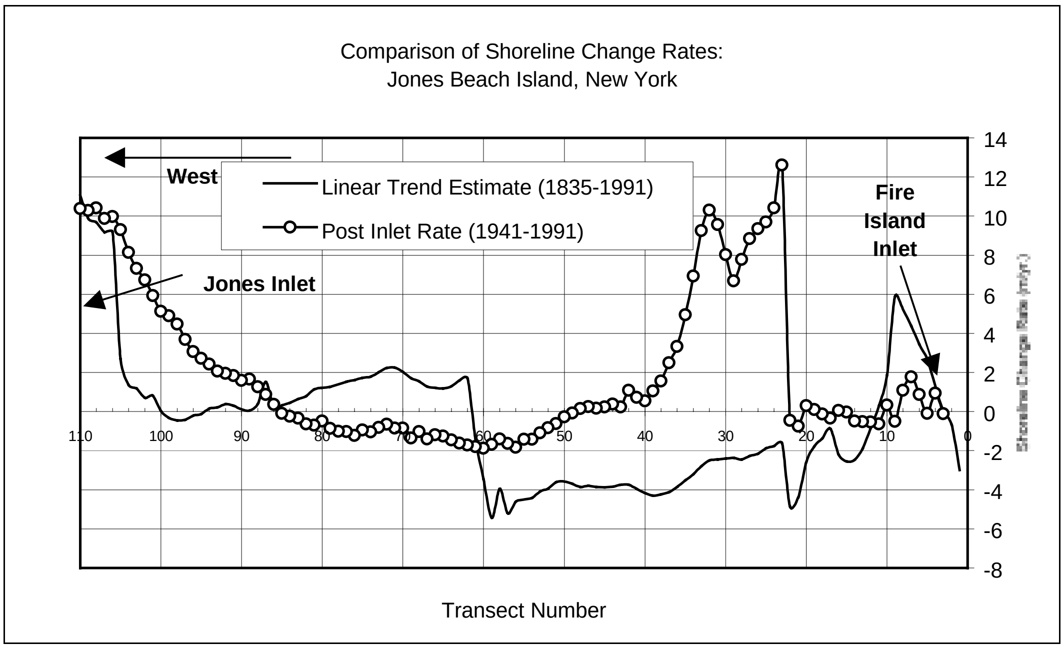

Figure 7. Shoreline change rates, Jones Beach Island

Standing and random longshore sand waves. Gravens (1999) documented undulations in the shoreline (Fig. 9) of Fire Island, Long Island, NY that are fixed in space, which might be thought of as standing waves, as opposed to translatory LSWs (Type 15). He developed a methodology for describing their dynamics through an independent-wave analysis, from which a root-mean-square deviation in shoreline position at a fixed location alongshore can be calculated. Gravens (1999) gave recommendations to account for shoreline undulations in beach fill design. Understanding of the temporal and spatial behavior of these in a beach-fill design allows planners to make a decision to mediate or to wait and accept the temporary recession. Increasing the volume of the dune as a safeguard and/or placement of a sacrificial berm in a fill are possible remediation measures. The cause of shoreline undulations is unknown, but it is hypothesized that seasonal wave direction and propagation over irregular bathymetry may play a role.

Figure 8. Longshore sand waves west of Mecox Bay, Long Island NY
(Photograph courtesy of First Coastal Corp.)

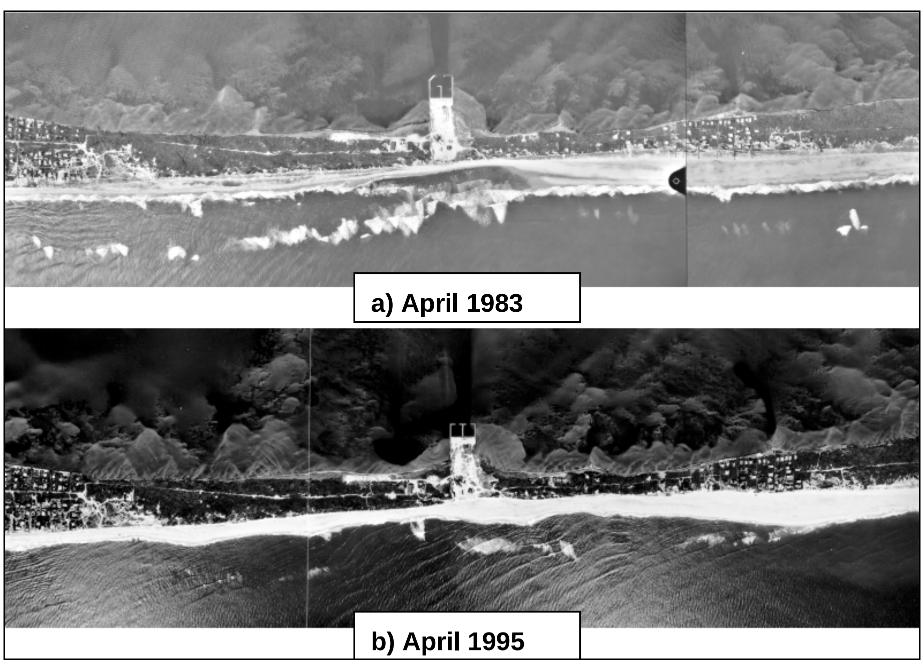

Figure 9. Shoreline undulation at Fire Island, Long Island, NY (Gravens 1999)

Isolation of beach from longshore transport inputs. Beaches located between the downdrift jetty of an inlet and the attachment bar may become isolated from significant sediment inputs. As depicted in Fig. 10, sand from the predominant transport direction will bypass the beach and continue downdrift, whereas the large attachment bar will tend to act as a groin and block sand from reaching the beach during transport reversals. At the beach, sand can move alongshore and toward the attachment bar or toward the jetty. Offshore transport during storms and loss of material into the navigation channel by a rip current near the jetty also removes sand. The beach thus tends to lose more sand than it can gain. A solution is placement of composite structures to hold the local beach (Hanson and Kraus 2001).

Figure 10. West side of Shinnecock Inlet, Long Island, NY, 26 October 1996

Rip currents on open beach, and near jetties and groins. Strong rip currents remove material from the surf zone and transport it offshore. Komar (1999, pp. 470-472) reviews the literature of embayments created by rip currents on the open coast. Development of rip current embayments along the Oregon coast is a primary factor in the erosional loss of property on foredunes on sand spits and in cutting away of sea cliffs backing beaches.

Rip currents tend to form and persist next to piers, groins, and jetties. Dolan et al. (1987) estimated that about 75,000 m^3/year of sediment was lost from the Oceanside, CA, littoral cell by seaward deflection of the longshore current at harbor structures and by rip currents along the open beach. Much of this material seems to have been deposited far offshore.

CONCLUDING DISCUSSION

Considerable information is available to predict, prevent, mitigate, and account for EHSs. Some causes of EHSs cover large space and time scales (Table 2) and cannot be remedied by typical means. Other types of EHSs are temporary and can either be mitigated or allowed to run their course. Table 3 gives example remedial measures that can be taken and are consistent with the cause (Table 1) and transport processes and scales (Table 2) of the type of EHS.

Table 3. EHS type and possible preventative and remediative measures[1]

Type	Prevention and Remediation
1. Dredge selectivity	Take coarsest sand at borrow site; be consistent; cap with coarser sand
2. Residual structure-induced slope	Account for differential volume requirements at the initial placement to allow the slope to reach equilib.
3. Wave transformation over borrow pit	Dredge shallow and as far offshore and in longest linear segments parallel to shore as possible
4. Gaps in bars	Recognize temporary nature; be prepared for addition of extra fill if not acceptable; fill dunes and/or berm
5. Mechanically placed fill	Ensure that fill volume and density are consistent with hydraulically placed fill or material on adjacent beaches
6. Profile lowering in front of seawalls or cliffs	Have trigger for renourishment before shoreline reaches seawall; be prepared for additional fill
7. Headlands and encroachments	For discontinuities and headlands, either do not fill in area or hold[2] the fill with structures. For unfavorable shoreline orientation, hold the fill with structures
8. Residual fill bathymetry	Reduce irregularities in fill planform;
9. Permanent offshore loss	Fill with coarser sand; attempt to redirect rip current, as through submerged dikes or perched beaches
10. Non-uniform offshore translation of beach fill	Compensate with overfill and/or accept the temporary accelerated loss behavior
11 Wave transformation over non-uniform offshore bathymetry	Compensate with overfill and/or accept the loss
12. Borrow pit located within active profile	Evaluate and compare maintenance for a borrow pit site located close to shore versus a site farther offshore; predict consequences and plan to mitigate
13. Updrift barrier	Periodically nourish; place sand-retention structures in severe situations
14 Relict inlet offsets	Compensate with additional fill volume; periodic nourishment
15. Translatory longshore sand waves	Estimate speed of wave; mitigate if necessary
16. Standing and random longshore sand waves	Quantify swings; overfill
17. Isolation of beach from longshore transport inputs	Place sand-retention structures and provide feeder site (nourishment) as necessary
18. Rip currents	Near structures, consider spur to deflect current laterally; otherwise, no known remediation

1) Several preventative and remediation measures taken from Dean, Liotta, and Simon (1999) and from Bodge, Gravens, and Srinivas (1999)

2) "Hold fill" preserves a design rate of loss while also feeding down-drift beaches

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